Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050

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Purpose: Myopia is a common cause of vision loss, with uncorrected myopia the leading cause of distance vision impairment globally. Individual studies show variations in the prevalence of myopia and high myopia between regions and ethnic groups, and there continues to be uncertainty regarding increasing prevalence of myopia.

Design: Systematic review and meta-analysis.

Methods: We performed a systematic review and meta-analysis of the prevalence of myopia and high myopia and estimated temporal trends from 2000 to 2050 using data published since 1995. The primary data were gathered into 5-year age groups from 0 to ≥100, in urban or rural populations in each country, standardized to definitions of myopia of −0.50 diopter (D) or less and of high myopia of −5.00 D or less, projected to the year 2010, then meta-analyzed within Global Burden of Disease (GBD) regions. Any urban or rural age group that lacked data in a GBD region took data from the most similar region. The prevalence data were combined with urbanization data and population data from United Nations Population Department (UNPD) to estimate the prevalence of myopia and high myopia in each country of the world. These estimates were combined with myopia change estimates over time derived from regression analysis of published evidence to project to each decade from 2000 through 2050.

Results: We included data from 145 studies covering 2.1 million participants. We estimated 1406 million people with myopia (22.9% of the world population; 95% confidence interval [CI], 932−1932 million [15.2%−31.5%]) and 163 million people with high myopia (2.7% of the world population; 95% CI, 86−387 million [1.4%−6.3%]) in 2000. We predict by 2050 there will be 4758 million people with myopia (49.8% of the world population; 3620−6056 million [95% CI, 43.4%−55.7%]) and 938 million people with high myopia (9.8% of the world population; 479−2104 million [95% CI, 5.7%−19.4%]).

Conclusions: Myopia and high myopia estimates from 2000 to 2050 suggest significant increases in prevalences globally, with implications for planning services, including managing and preventing myopia-related ocular complications and vision loss among almost 1 billion people with high myopia. *Ophthalmology 2016;123:1036-1042 © 2016 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

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In 2010, it was estimated that uncorrected refractive error was the most common cause of distance vision impairment, affecting 108 million persons, and the second most common cause of blindness globally.[1] The economic burden of uncorrected distance refractive error, largely caused by myopia, was estimated to be US$202 billion per annum.[2] There is a substantive economic argument for eliminating uncorrected myopia and other refractive errors.[3]

However, myopia brings further vision challenges because high myopia increases the risk of pathologic ocular changes such as cataract, glaucoma, retinal detachment, and myopic macular degeneration, all of which can cause irreversible vision loss.[4] In some communities with a high prevalence of myopia, myopic macular degeneration has been found to be the most frequent cause of irreversible blindness.[5] Myopic macular degeneration has been found to cause 12.2% of vision impairment in Japan (approximately 200 000 people).[6]

There remain 2 major gaps in the literature. First, individual studies suggest wide variation in the prevalence of myopia between different regions and ethnic groups.[7] For example, the prevalence of myopia is more than 2 times higher among East Asians than similarly aged white persons.[8] Second, the prevalence of myopia in different countries seems to be increasing, and most dramatically among younger people in East Asia.[8] The combination

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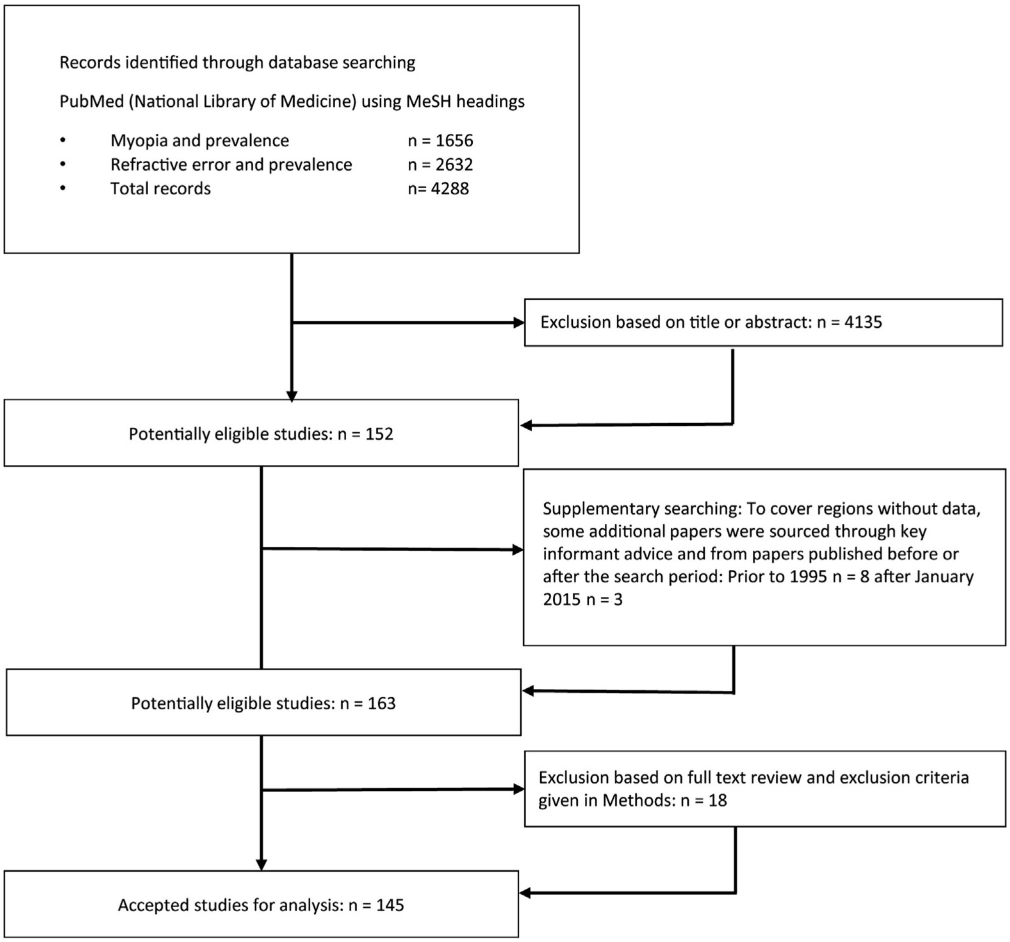

Figure 1. Flow diagram summarizing the systematic search and review process for identifying myopia prevalence evidence globally. MeSH = medical subject headings.

of vision impairment from uncorrected myopia and irreversible vision loss from myopia-related complications make accurate global estimates of the prevalence and temporal trends critical for planning care and services. However, there are no precise estimates of the global prevalence of myopia or for projected temporal changes over the next few decades.

Methods

Studies, Databases, and Data Organization

We performed a systematic search and review of the prevalence of myopia and high myopia using data published since 1995, summarized in Figure 1. We searched PubMed (National Library of Medicine) on January 10, 2015, for publications using the following MeSH (Medical Subject Heading) terms: *myopia* AND *prevalence* and *refractive error* AND *prevalence*. The search was restricted to articles published after January 1, 1995, and was performed on all available articles regardless of the original language of publication. The search yielded 1656 and 2632 articles relating to myopia and refractive error, respectively. The abstract of each publication was reviewed and articles that were population-based surveys were included. Surveys were excluded if they did not specify the number of eligible participants or participation rate, or if data were from a specific population that could not be generalized to the population as a whole. We rejected 8 articles that did not specify a definition of myopia. To cover regions without data, some additional articles were sourced through key informant advice and from reference lists of articles found through PubMed. A full list of the 145 studies is included in Appendix 1 (available at www.aaojournal.org).

Country-specific population data for each decade from 2000 through 2050, in 5-year age groups from 0 to $\geq$100, were drawn mostly from the United Nations World Population Prospects.[9] Population data from the United States Census Bureau were used for a small number of low-population states omitted from the available United Nations data.[10]

Studies have suggested that myopia rates differ in urban compared with rural communities that are otherwise similar.[11,12] We therefore obtained separate urban and rural myopia prevalences where possible and disaggregated country-level populations into urban and rural numbers sourced from the United Nations World Urbanization Prospects.[13]

Countries were grouped into the 21 Global Burden of Disease (GBD) regions.[1] The country-specific urban and rural population data were combined with the corresponding prevalence data in each 5-year age group to calculate the number of people with myopia. The numbers of people with myopia in each age group in rural and urban areas of each country then were aggregated to obtain regional totals.

Definitions

The definitions of myopia and high myopia vary across the selected prevalence studies. Of the 145 articles included in this study, the most common definition of myopia was spherical equivalent of −0.50 diopter (D) or less (58.7%), with 29.0% using less than −0.50 D, 5.0% using −1.00 D or less or less than −1.00 D (all studies of adults), 2.9% using −0.75 D or less or less than −0.75 D, and 3.6% using −0.25 D or less or less than −0.25 D. Only 59 studies defined and measured high myopia, with 30.5% defining it as −6.00 D or less, 30.5% defining it as less than −6.00 D, 35.6% defining it as −5.00 D or less or less than −5.00 D, 1.7% defining it as −8.00 D or less, and 1.7% defining it as −3.00 D or less.

We standardized to a spherical equivalent of −0.50 D or less for myopia because it was the most commonly used definition in published prevalence studies, is beyond refraction measurement error, and captures children at the start of their progression. We standardized to a spherical equivalent of −5.00 D or less for high myopia because it is used commonly, identifies people at higher risk of pathologic myopia, and if uncorrected, causes vision impairment at least equivalent to the World Health Organization−defined blindness.[14]

The relationship between prevalence and definition was analyzed using all articles providing prevalence at 2 or more cut-offs for myopia or high myopia. All prevalence data were standardized to myopia and high myopia definitions of −0.50 D or less and −5.00 D or less, respectively, using linear regressions specific to regional and dioptric level (see Supplemental Material, part 1, available at www.aaojournal.org).

Meta-analysis and Extrapolation

Meta-analysis of the prevalence of myopia and high myopia within each age group of each GBD region, using the standardized myopia definitions and a standardized time point of 2010, was performed using Comprehensive Meta-Analysis software version 3 (Biostat, Englewood, NJ). A logit random effects model was used to combine studies within each age group and region. The logit prevalence was defined as $\log(p/(1-p))$, where p is the prevalence within each age group. The study-to-study variance (τ^2) was not assumed to be the same for all age groups within the region, indicating that this value was computed within age groups and was not pooled across age groups. The inverse of the variance was used to compute relative weights. The logit prevalence and its standard error were used to compute the 95% confidence limits, which then was transformed to the estimated prevalence and its corresponding limits using the formula $E\hat{}$(logit prevalence)/($E\hat{}$(logit prevalence) + 1), where E = Euler's number.

Age-specific regional meta-analysis results were extrapolated to GBD regions lacking data in any specific age or urbanization group, with extrapolations based on regional similarities in urbanization, Human Development Index (HDI), racial profiles, culture, education systems, health systems, and other similarities.[15] Data gaps within regions also were filled via nearest neighbor linear interpolation between age groups up to a maximum of 20 years between groups.

Projections across Decades

Longitudinal and repeated cross-sectional studies have shown increasing prevalence of myopia.[16−21] We analyzed change in myopia prevalence over time against prevalence of myopia ($R^2 = 0.86$), rate of urbanization ($R^2 = 0.07$), and change in HDI ($R^2 = 0.69$). The relationship between change in myopia over time and prevalence of myopia was the strongest, following the formula:

$$\text{Percentage annual prevalence change} = 12.456 \times E\hat{}(-0.04 \times \text{prevalence}) - 0.22813,$$

where E = Euler's number. There were 2 exceptions to using this percentage annual change formula. First, because there were no data for prevalence less than 28.3%, we took the conservative approach of using a constant 3.8% change/year for all prevalences less than 28.3%. Second, Vitale et al[16] provide a clear indication that the effect decreases at ages younger than 20 years. Fitting a 2-part linear function to their data suggested adjusting the calculated annual change in myopia figure by a factor of 0.5 in the 10- to 19-year-old age groups, 0.25 in the 5- to 9-year-old age group, and 0 in the 0- to 4-year-old age group. The prevalence of myopia in each decade was calculated by adjusting the prevalence figure by a cumulative change equal to Prevalence × (1 + (Percentage annual change)^(number of years)).

Three studies showed a similar increase in prevalence of high myopia over time. Given the sparse data, we used a simple average annual prevalence change from these studies (3.26% per year).[16−18] Additionally, because the evidence trended to less annual change as prevalence increased between 15% and 30% and there was no annual change data for high myopia prevalence of 30% or more, we generated a logarithmic decay function that reduced to 0 when the prevalence reached 100%. This formula was used when the prevalence of high myopia was more than 30%:

$$\text{Annual change} = -2.237 \times ln(\text{prevalence}) + 10.283,$$

where ln = natural log. Data from Vitale et al[16] again suggested that the annual change in high myopia prevalence would be less in age groups younger than 20 years. Using a similar process as in the myopia case, the annual change in high myopia prevalence was adjusted by a factor of 0.4 in the 15- to 19-year-old age group, 0.3 in the 10- to 14-year-old age group, 0.2 in the 5- to 9-year-old age group, and 0.1 in the 0- to 4-year-old age group. The changing proportion of people living in urban versus rural situations in each decade was sourced from the United Nations.[13]

Confidence Intervals

In addition to the 95% confidence limits calculated in the meta-analysis of prevalence data, uncertainty in future population projections was represented by the high- and low-fertility population projections from the United Nations.[13]

Control Factors

Published evidence indicates that myopia is common and increasing over time, with apparent effects of race, location, and generation. Racial effects were controlled by using studies as broadly representative of a country's population as possible and extrapolating within GBD regions. Location effects were controlled by disaggregating urban and rural populations and prevalence and extrapolating based on HDI and GBD region. Generational shifts were accommodated through our change over time methodology and were facilitated by maintaining 5-year age groups through to ≥100.

Results

A summary of the original data from all 145 studies is given in Appendix 2 (available at www.aaojournal.org). Figure 2 shows our estimates of the total number of people with myopia globally. In

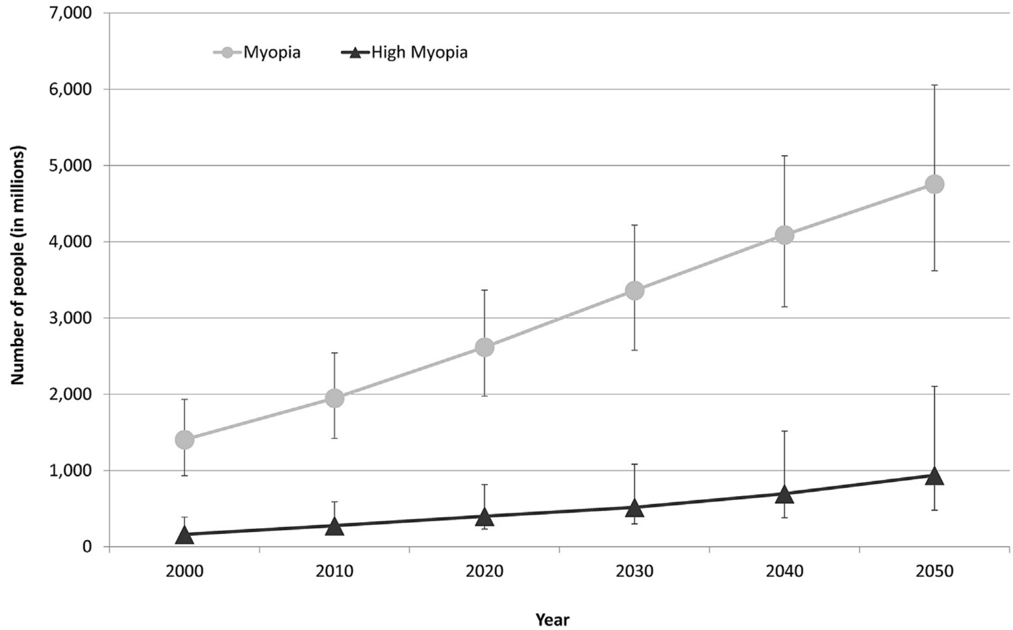

Figure 2. Graph showing the number of people estimated to have myopia and high myopia for each decade from 2000 through 2050. Error bars represent the 95% confidence intervals.

2000, this was 1406 million (22.9% of the global population; uncertainty interval, 932–1932 million [15.2%–31.5%]), increasing to 1950 million in 2010 (28.3% of the global population; 1422–2543 million [20.6%–36.9%]). This is projected to increase to 2620 million in 2020 (34.0% of the global population; uncertainty interval, 1976–3366 million [26.2%–42.6%]), to 3361 million by 2030 (39.9% of the global population; uncertainty interval, 2578–4217 million [32.3%–47.5%]), to 4089 million by 2040 (45.2% of the global population; uncertainty interval, 3145–5128 million [38.1%–52.1%]), and to 4758 million by 2050 (49.8% of the global population; uncertainty interval, 3620–6056 million [43.4%–55.7%]).

Regional differences are evident throughout the projection period, as shown in Table 1. The high-income countries of Asia-Pacific begin with a significantly higher prevalence of myopia than any other region. East Asia, Southeast Asia, and the high-income countries of North America close the gap to some extent by 2050 because of a combination of ceiling effects in some age groups, prevalence distribution across age groups, and changing age demographics.

Figure 2 shows our estimates of the total number of people with high myopia globally. This was 163 million in 2000 (2.7% of the global population; uncertainty interval, 86–387 million [1.4%–6.3%]), increasing to 277 million in 2010 (4.0% of the global population; uncertainty interval, 153–589 million [2.2%–8.6%]). This is projected to increase to 399 million in 2020 (5.2% of the global population; uncertainty interval, 233–815 million [3.1%–10.3%]), to 517 million by 2030 (6.1% of the global population; uncertainty interval, 298–1082 million [3.7%–12.2%]), to 696 million by 2040 (7.7% of the global population; uncertainty interval, 381–1518 million [4.6%–15.4%]), and to 938 million by 2050 (9.8% of the global population; uncertainty interval, 479–2105 [5.7%–19.4%]). Regional differences are evident throughout the projection period, as shown in Table 1.

Figure 3 shows the distribution of people with myopia and prevalence of myopia across age groups. In 2000, the greatest numbers of people with myopia were between 10 and 39 years of age. However, our projections suggest that through both cohort and age effects this distribution will spread by 2050, with large numbers of people with myopia from 10 years of age all the way through to 79 years of age.

Table 1. Prevalence of Myopia Estimated for Each Global Burden of Disease Region between 2000 and 2050

Region	Prevalence (%) in Each Decade					
	2000	2010	2020	2030	2040	2050
Andean Latin America	15.2	20.5	28.1	36.2	44.0	50.7
Asia-Pacific, high income	46.1	48.8	53.4	58.0	62.5	66.4
Australasia	19.7	27.3	36.0	43.8	50.2	55.1
Caribbean	15.7	21.0	29.0	37.4	45.0	51.7
Central Africa	5.1	7.0	9.8	14.1	20.4	27.9
Central Asia	11.2	17.0	24.3	32.9	41.1	47.4
Central Europe	20.5	27.1	34.6	41.8	48.9	54.1
Central Latin America	22.1	27.3	34.2	41.6	48.9	54.9
East Africa	3.2	4.9	8.4	12.3	17.1	22.7
East Asia	38.8	47.0	51.6	56.9	61.4	65.3
Eastern Europe	18.0	25.0	32.2	38.9	45.9	50.4
North Africa and Middle East	14.6	23.3	30.5	38.8	46.3	52.2
North America, high income	28.3	34.5	42.1	48.5	54.0	58.4
Oceania	5.0	6.7	9.1	12.5	17.4	23.8
South Asia	14.4	20.2	28.6	38.0	46.2	53.0
Southeast Asia	33.8	39.3	46.1	52.4	57.6	62.0
Southern Africa	5.1	8.0	12.1	17.5	23.4	30.2
Southern Latin America	15.6	22.9	32.4	40.7	47.7	53.4
Tropical Latin America	14.5	20.1	27.7	35.9	43.9	50.7
West Africa	5.2	7.0	9.6	13.6	19.7	26.8
Western Europe	21.9	28.5	36.7	44.5	51.0	56.2
Global	22.9	28.3	33.9	39.9	45.2	49.8

Numbers and uncertainty are provided in the Supplemental Material (available at www.aaojournal.org).

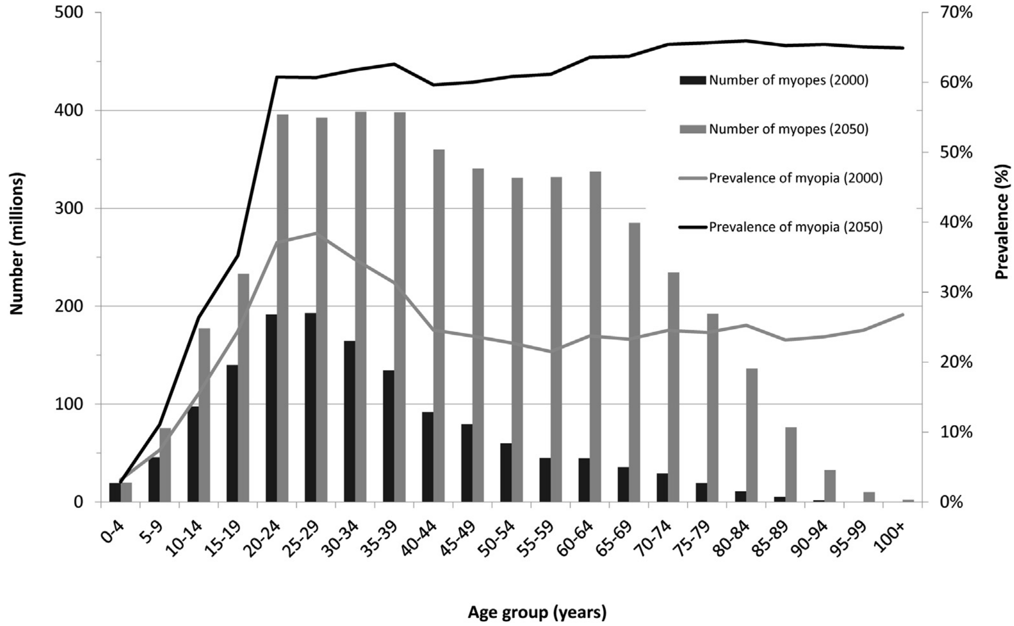

Figure 3. Graph showing the distribution of people estimated to have myopia across age groups in 2000 and 2050.

Discussion

Our study estimates that myopia and high myopia will show a significant increase in prevalence globally, affecting nearly 5 billion people and 1 billion people, respectively, by 2050. These have important implications for planning comprehensive eye care services, including refractive services such as spectacles and managing and preventing myopic-related ocular complications and vision loss among people with high myopia.

The increasing prevalence of high myopia has already been noted in some regions. Vitale et al[16] found an 8-fold increase in high myopia ($\leq$7.90 D) over 30 years, from 0.2% to 1.6%.[16] The level of high myopia in Asian countries is considerably higher. In the study of college freshman in Taiwan by Wang et al,[19] high myopia increased from 26% of all myopia in 1988 to 40% of myopia in 2005. Lin et al[17] found that 21% of 18-year-old Taiwanese students in 2000 had high myopia (<-6.00 D) compared with 10.9% in 1983.

The projected increases in myopia and high myopia are widely considered to be driven by environmental factors (nurture), principally lifestyle changes resulting from a combination of decreased time outdoors and increased near work activities, among other factors.[22] Genetic predisposition also seems to play a role, but cannot explain the temporal trends observed over a short period.[23] Among environmental factors, so-called high-pressure educational systems, especially at very young ages in countries such as Singapore, Korea, Taiwan, and China, may be a causative lifestyle change, as may the excessive use of near electronic devices.[22] Other proposed causes include light levels,[24] which may be directly related to time outdoors, with peripheral hyperopia in the myopic eye (corrected and uncorrected) encouraging axial growth,[25] and diet.[26] The global myopia in the year 2000 values in Figure 3, with the bulk of myopia in age groups younger than 40 years, reflects the significant lifestyle changes for children and young people over the past 10 to 25 years, especially in the large population centers of Asia.

Our projections, based on existing data, assume that these lifestyle changes will continue to spread with increasing urbanization and development. Accelerated changes, or reversal of recent trends, would be expected to increase or decrease future prevalence from our predictions, respectively. Our projections indicate that by 2050, 50% and 10% of the world will have myopia and high myopia, respectively, a 2-fold increase in myopia prevalence (from 22% in 2000) and a 5-fold increase in high myopia prevalence (from 2% in 2000). Higher amounts of myopia have the potential to cause vision impairment by myopic macular degeneration or its comorbidities, cataract, retinal detachment, and glaucoma,[27] the risk of which increase with any increase in myopia. Based on our projections and assuming the proportion of those with high myopia who go on to experience vision loss resulting from pathologic myopia remains the same, the number of people with vision loss resulting from high myopia would increase 7-fold from 2000 to 2050, and myopia would become a leading cause of permanent blindness worldwide. This is a conservative estimate; Figure 3 shows not only that will there be more people with myopia by 2050, but also that they will also be older and more susceptible to the pathologic effects of myopia than in 2000.

Our study design has some potential limitations. The first is the paucity of prevalence data in many countries and age groups, across representative geographic areas, racial groupings, and HDIs. This problem was greater for high myopia than myopia. The further the primary data are extrapolated, the greater the uncertainty of the estimates becomes. Second, many countries and age groups across representative geographic areas, racial groupings, and HDIs lacked data on the change in myopia, especially high myopia, over time. Local effects on changes in myopia over time are potentially lost when annual changes are extrapolated across regions. However, Vitale et al[16] noted that the myopia and high myopia changes seen in African Americans were very similar to those in European Americans, suggesting that although environmental changes are important, racial differences probably are not. Third, projecting on the basis of current information has the potential to miss varying changes over time. Fourth, variations in the definition of myopia and high myopia in the evidence base made it necessary to adjust each prevalence we used to a standard definition, which increases uncertainty. There are conflicting data on the effect of gender on myopia prevalence. For example, Wu et al[28] found that girls in urban China were significantly more likely to have myopia than boys, whereas Hashemi et al[29] found the opposite to be true. With these sorts of conflicts, it seems unlikely that there is a simple gender effect on myopia development. There may be a more complex gender effect, where differential access to, encouragement to participate in, or choices with respect to education, outdoor activities, light exposure, or a combination thereof between boys and girls influences the development of myopia. We believed that this kind of gender effect was beyond the scope of this study, so we did not disaggregate based on gender. Also, we used a logarithmic decay function to estimate the future prevalence of myopia, and thus it is possible that future prevalence may have been overestimated, especially for regions where the current prevalences are moderate to low. However, given that there is an element of uncertainty associated with estimating future prevalences, regardless of the model or function used to derive estimates, drawbacks are likely to exist. More relevant is the clear evidence for a rising global prevalence of myopia, and thus these estimates simply indicate that if it continues on its present course, the future burden of myopia is likely to be substantial.

Because of the relatively common nature of myopia, even population studies with relatively small sample sizes can offer useful information provided the samples are representative. Other strengths include the large number of good-quality studies that have been performed in the regions that have both the highest prevalence of myopia and the largest populations (for example, East Asia, Asia-Pacific high income, and South Asia), our clear definitions and methods of standardizing source data, our analysis of the change in myopia over time, and our methods of calculating projected change.

We have not taken into account the effect of myopia control interventions that may take place between now and 2050. These would aim to reduce substantially the prevalence of high myopia. Interventions that sufficiently slow or delay myopia have the potential to prevent an individual developing high myopia, provided treatment is started early enough. Changes in lifestyle, successive improvement, and the uptake of myopia control could substantially reduce the number of people with myopia and high myopia. The uptake of myopia control, however, requires a strong evidence base and a concerted effort by government, education, and health systems.

In conclusion, our systematic review, meta-analysis, and projections provide myopia and high myopia predictions through 2050 and their distribution between GBD regions. Our estimates and projections assimilate local, individual studies into an improved global understanding of myopia epidemiologic factors. Our methodology provides a basis for validation of projections against new evidence as it is published. If correct, our projections have significant implications for planning comprehensive eye care services globally, which would need to cater to close to 1 billion people with high myopia by 2050, 7.5 times more than in 2000. The benefits of a multifaceted myopia control system to buffer this scenario would be substantial.

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Footnotes and Financial Disclosures

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Abbreviations and Acronyms:
D = diopter; **GBD** = Global Burden of Disease; **HDI** = Human Development Index.

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